

Cloud Absorption Properties as Derived from Airborne Measurements of Scattered Radiation within Clouds

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1. Introduction

A multiwavelength scanning radiometer has been developed for measuring the angular distribution of scattered radiation deep within a cloud layer (King *et al.*, 1986). The purpose of this instrument is to provide measurements from which the similarity parameter of clouds can be derived as a function of wavelength, where the similarity parameter is a function of cloud single scattering albedo and asymmetry factor. The cloud absorption radiometer flew on the University of Washington's Convair-131A aircraft during the marine stratocumulus intensive field observation component of the First ISCCP Regional Experiment (FIRE), conducted off the coast of San Diego, California during July 1987. The instrument was flown as one of a group of instruments that included upward and downward looking pyranometers, cloud microphysics probes for measuring the cloud particle size distribution and liquid water content, and an air batch sampler for measuring the cloud interstitial aerosol size distribution (Radke, 1983).

The cloud absorption radiometer has been built, flight tested and flown on the University of Washington C-131A aircraft during 8 flights of the marine stratocumulus intensive field observation phase of FIRE. We have thus far concentrated our attention on aspects of three of these flights, two of which were flown in coordination with the UK Meteorological Research Flight C-130 aircraft and one in coordination with the NASA ER-2 aircraft. The C-130 contained a 16 channel, fixed-angle, multispectral cloud radiometer, with 8 channels in the visible and near-infrared region and 8 channels in the thermal infrared (Foot, 1988), while the ER-2 contained a 7 channel scanning radiometer for the purpose of deriving the cloud optical thickness, effective particle radius, and cloud top altitude (Curran *et al.*, 1981; King, 1987).

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In this paper, we briefly review the diffusion domain method for deriving the cloud similarity parameter and present preliminary analyses of the results thus far obtained. Our presentation will concentrate on the following points:

- (1) Intercomparison of calibrated reflected intensities between the cloud absorption radiometer and the UK multispectral cloud radiometer,
- (2) Quality control tests required to select those portions of an aircraft flight for which measurements are obtained within the diffusion domain,
- (3) Case studies of the spectral similarity parameter of marine stratocumulus clouds,
- (4) Comparisons of the experimentally-derived similarity parameter spectrum with that expected theoretically from the cloud droplet size distribution obtained from *in situ* observations.

2. Calibration

The Goddard Space Flight Center multispectral cloud radiometer (MCR) and cloud absorption radiometer (CAR) were calibrated using a laboratory calibration facility consisting of a 6 ft integrating sphere and a 4 ft integrating hemisphere. The absolute calibrations of the integrating sphere and hemisphere are determined about once every 6 months by a calibration branch at Goddard and somewhat less frequently by an outside laboratory (Optronic Laboratories). After considerable examination of the experimental data from these two instruments and the absolute lamp intensities from both laboratories, we were able to determine our best estimate of the absolute calibration coefficients for both instruments at their respective wavelengths (13 for the CAR and 6 near-infrared channels for the MCR). Thus the first quantitative examination of the radiation data from the FIRE flights centered on comparing the absolute reflected intensities of the CAR and the UK multispectral cloud radiometer during three simultaneous wing-tip intercomparisons during two flights.

Figs. 1-3 illustrate the nadir reflected intensities as measured by the UK multispectral cloud radiometer and the GSFC cloud absorption radiometer on each of these intercomparison flights. Since the gains of the CAR were adjusted for internal cloud radiation measurements, some of the filter wheel channels (channels 8-13, $1.55 \leq \lambda \leq 2.29 \mu\text{m}$) were saturated. By careful examination of these figures, especially Fig. 2, one can see the spectral reflection signature of the clouds quite clearly. The C-130 radiometer has channels in a couple of water vapor bands (1.33 and $1.85 \mu\text{m}$), whereas the Goddard CAR has all channels in water vapor window regions. Thus, in combination, the entire reflected spectrum of these clouds is quite apparent.

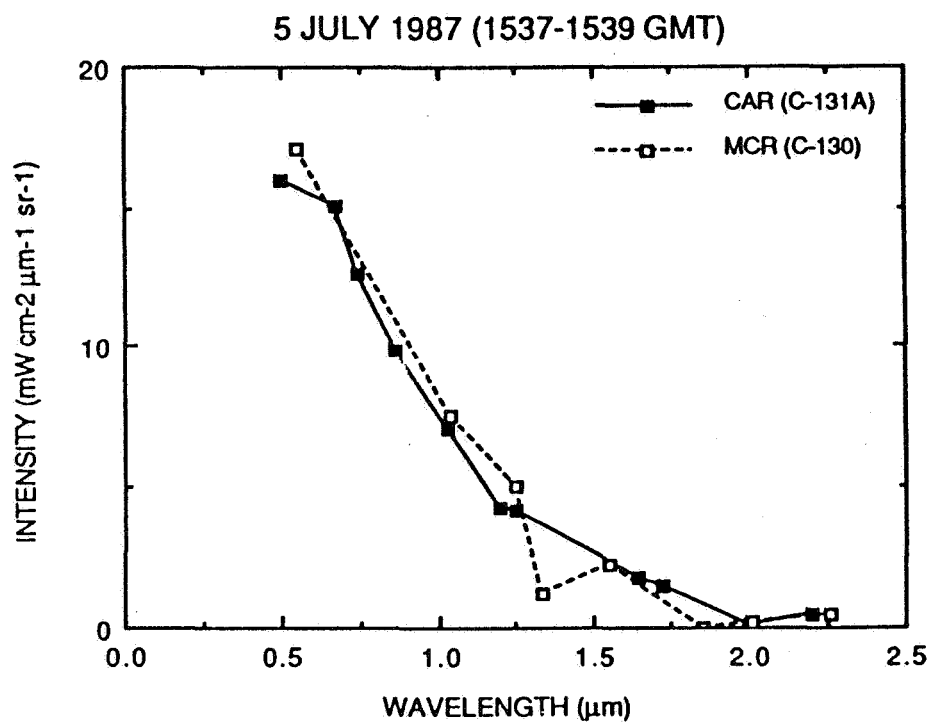


Fig. 1. Intercomparison of the nadir reflected intensity of marine stratocumulus clouds as measured by the UK multispectral cloud radiometer and the GSFC cloud absorption radiometer on 5 July 1987 (1544-1546 GMT).

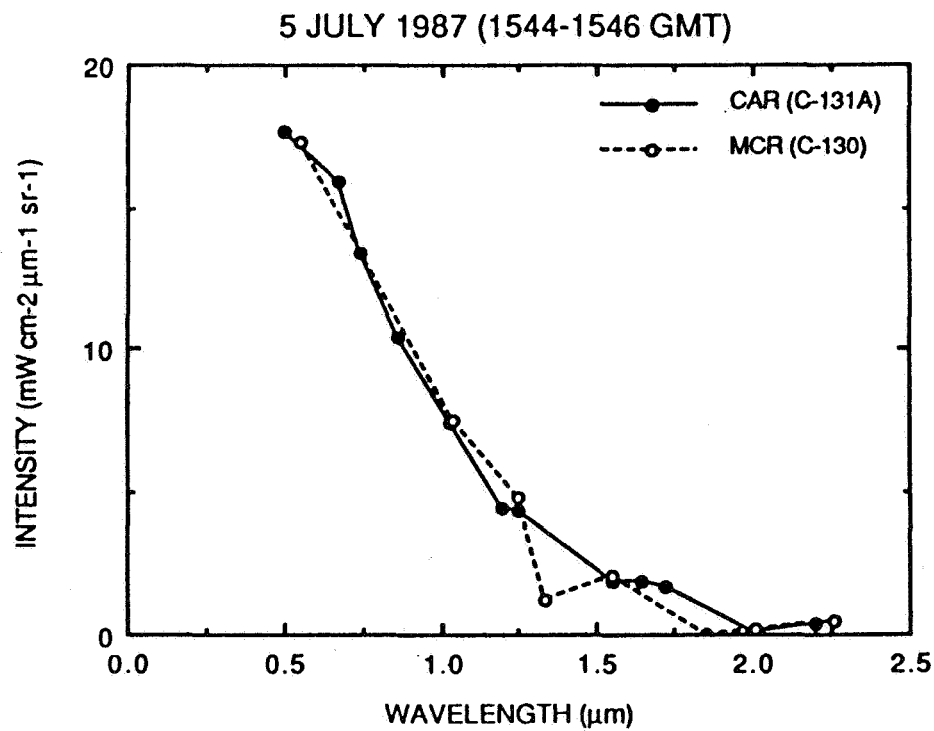


Fig. 2. As in Fig. 1 except for 1544-1546 GMT.

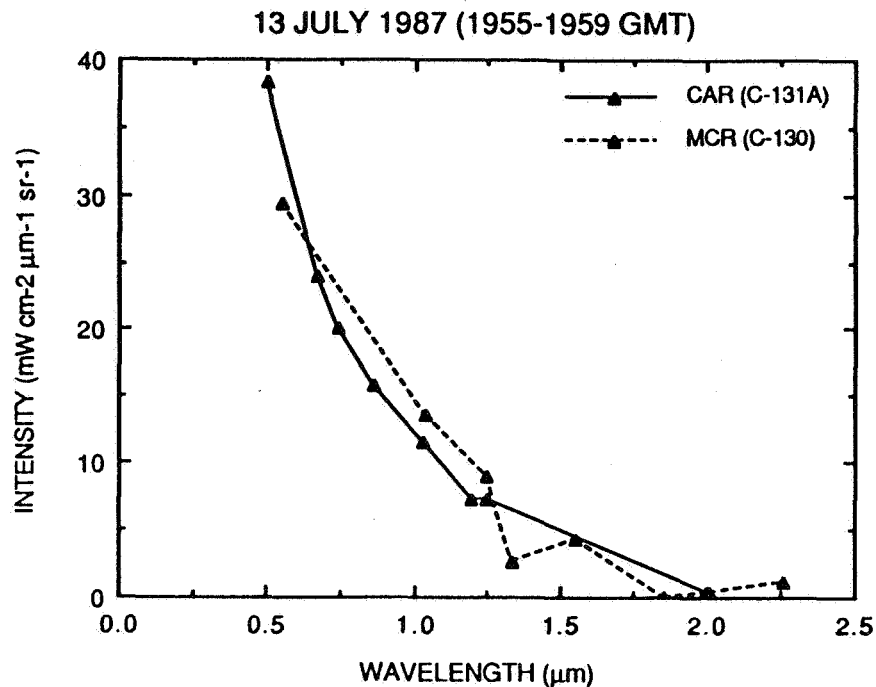


Fig. 3. As in Fig. 1 except for 13 July 1987 (1955-1959 GMT).

The longest intercomparison occurred on 13 July 1987, for which the C-130 and C-131A flew wing-tip to wing-tip for 3.41 min (16.4 km). Fig. 4 illustrates the zenith (skylight) and nadir (reflected) intensities as a function of time for channel 2 ($\lambda = 0.67 \mu\text{m}$), where the dashed curve corresponds to the reflected intensity that was averaged and presented in Fig. 3. Since the solar zenith angle was 10.2° at the time of these measurements, the zenith intensity measurement was influenced by the solar aureole and was often saturated.

3. Diffusion domain measurements

On 10 July 1987 the C-130 flew a tightly coordinated mission with the ER-2 aircraft, consisting of continually flying legs of 130 km in length. The C-130 was primarily making cloud radiation and cloud microphysics measurements deep within the clouds. The determination of the cloud similarity parameter, defined as $s = [(1 - \omega_0)/(1 - \omega_0 g)]^{1/2}$, where g is the asymmetry factor and ω_0 the single scattering albedo, is based on making measurements of the ratio of the nadir to zenith intensity within the diffusion domain of a cloud. We have developed a comprehensive set of tests to which the CAR data are subjected in order to identify those portions of the flight for which measurements were obtained within the diffusion domain. On this particular day, our tests showed that a staggering 5380 scans (53.8 min, 266 km) met these criteria.

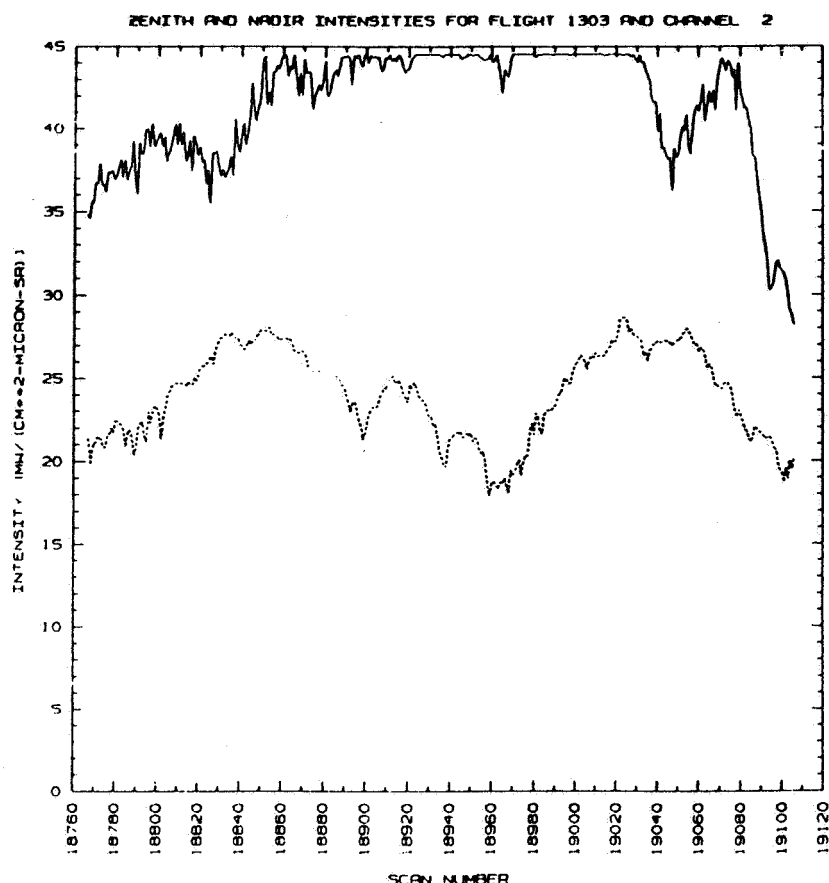


Fig. 4. Zenith and nadir intensities as measured by the cloud absorption radiometer for the wing-tip intercomparisons presented in Fig. 3. The solid curve represents the zenith (downward propagating) intensity and the dashed curve the nadir (reflected) intensity from the marine stratocumulus clouds. The abscissa is the CAR scan number (100 scans min^{-1}) and thus the time scale runs for 341 scans (3.41 min, 16.8 km).

Although we have not yet quantitatively analyzed these data to derive the similarity parameter spectrum, the time series of the zenith and nadir intensities for 1000 scan lines (10 min) of data, illustrated in Fig. 5 for $\lambda = 0.67 \mu\text{m}$, show that the zenith and nadir intensity field was quite uniform within these clouds. The method of analysis, described in detail by King (1981) and summarized by King et al. (1986), will be applied to these data and discussed in detail at the meeting.

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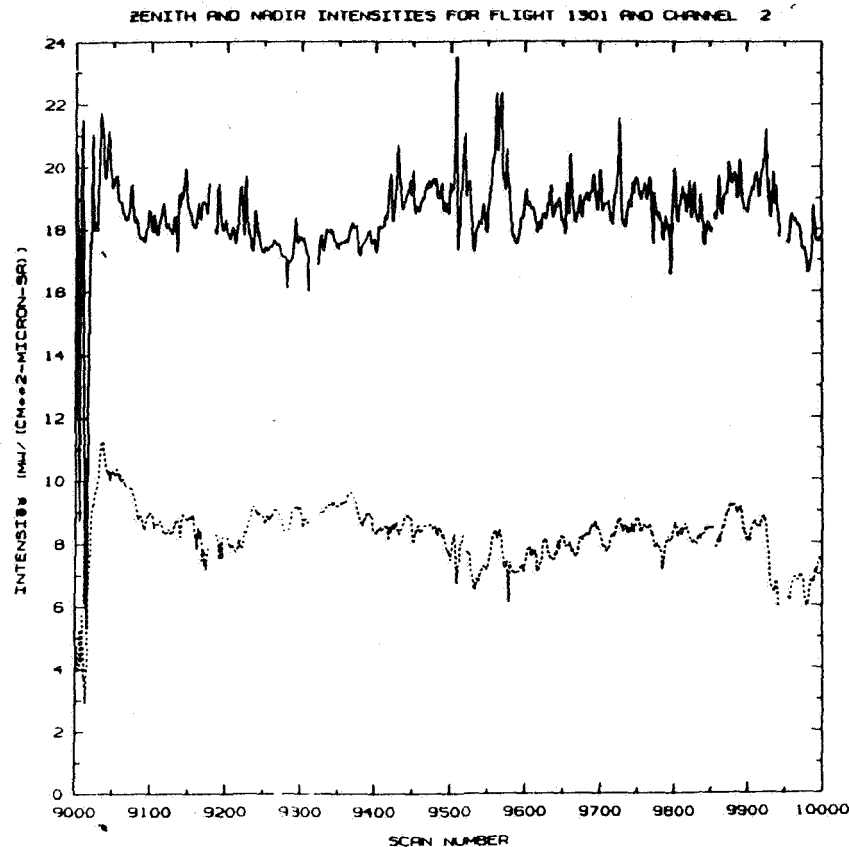


Fig. 5. As in Fig. 4 except for measurements within the diffusion domain of optically thick clouds as measured by the cloud absorption radiometer on 10 July 1987. The abscissa is the CAR scan number and runs for 1000 scans (49.4 km).

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